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Fixed-Frequency and Frequency-Agile (Au, HTS) Microstrip Bandstop Filters for L-Band Applications

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***Abstract*—In this work, we report on the performance of a highly selective, compact 1.83×2.08 cm^2 (~0.72×0.82 in.^{2}) microstrip line bandstop filter of $YBa_2Cu_3O_{7-\delta}$ (YBCO) on $LaAlO_3$ (LAO) substrate. The filter is designed for a center frequency of 1.623 GHz for a bandwidth at 3 dB from reference baseline of less than 5.15 MHz, and a bandstop rejection of 30 dB or better. The design and optimization of the filter was performed using Zeland's IE3D circuit simulator. The optimized design was used to fabricate gold (Au) and High-Temperature Superconductor (HTS) versions of the filter. We have also studied an electronically tunable version of the same filter. Tunability of the bandstop characteristics is achieved by the integration of a thin film conductor (Au or HTS) and the non-linear dielectric ferroelectric $SrTiO_3$ in a conductor/ferroelectric/dielectric modified microstrip configuration. The performance of these filters and comparison with the simulated data will be presented.**

***Index Terms*—L-band Bandstop Filter, High Temperature Superconducting (HTS) thin films, $LaAlO_3$ substrates, Ferroelectric thin films, tunable filters.**

I. Introduction

Since the discovery of High-Temperature Superconductors (HTS) in 1986, many HTS-based planar microwave components such as resonators and filters have been demonstrated. The use of these HTS films in place of normal conductors (e.g., gold and copper) has reduced conductor losses and consequently insertion loss. In recent years, HTS thin-film based filters have been seriously considered for applications in cellular and PCS communications, as well as for some specific radio-astronomy applications [1]–[4]. For example, HTS pre-select filters are currently being investigated in cellular base-stations for improved selectivity [2].

Also, HTS components have been integrated with ferroelectric thin films to develop low loss, frequency, and phase-agile microwave components [5]–[7]. For radio-astronomy applications, the L-band 21-cm hydrogen line (~1.428 GHz) is heavily utilized for deep space exploration. Because the spectrum is crowded at these frequencies, suppression of spurious signals is extremely necessary to avoid degradation of the probing frequency band of interest. Therefore, bandstop filters that offer small size, low loss, and ease of integration into the receiver subsystems while maintaining stringent specifications are highly desirable.

In this paper, we report on the performance of a highly selective, compact 1.83×2.08 cm^2 (~0.72×0.82 in.^{2}) bandstop microstrip line L-band filter fabricated using gold (Au) or $YBa_2Cu_3O_{7-\delta}$ (YBCO) thin films on $LaAlO_3$ (LAO). Two versions of the filter have been studied: a fixed-frequency design and a tunable design using a (Au, YBCO)/ $SrTiO_3$/LAO superconducting/ferroelectric/dielectric multilayer structure.

II. Design, Fabrication, and Testing

The bandstop filter was designed for symmetrical stop-band rejection at the center frequency of 1.623 GHz, with the stop-band 3 dB bandwidth (from reference base line) of 5.15 MHz or better. The stop-band rejection needed was ≥ 30 dB at the center frequency, and the passband insertion loss less than 1.0 dB below 1.614 GHz and above 1.634 GHz. To meet the above stringent specifications, the bandstop filter was designed from the traditional Chebychev low-pass prototype synthesis and transformation technique [8]. Due to the higher quality factor (Q) possible with superconductors, the minimum number of poles required was determined to be 3.

The bandstop filter was implemented using the microstrip edge-coupled resonators coupled to a through line. Desired band-rejection characteristics were obtained by optimizing the spacing between the through line and the resonators, and the length of the coupled sections, with the microstrip lines designed for 50 Ω characteristic impedance on 508 μm (20 mil) LAO substrates. The final optimization of the filter was performed using Zeland's IE3D electromagnetic simulators [9]. The schematic of the optimized filter is shown in Fig. 1. The performance of the filter as modeled using IE3D is shown in Fig. 2. The modeled data comply with all the aforementioned specifications for this filter.

The YBCO/$LaAlO_3$ filter considered in this work consisted of a 508 μm thick $LaAlO_3$ substrate with an area of 1.83×2.08 cm^2 coated with a 600 nm thick YBCO HTS film. The filter was fabricated using standard photolithography and chemical etching techniques. A gold (Au) version of the filter was also fabricated by depositing a Au thin film (~2.5 μm thick) on a $LaAlO_3$ substrate using e-beam evaporation. For both versions of the filter a 2.5 μm thick gold ground plane film was deposited on the side of the substrate opposite to the circuit.

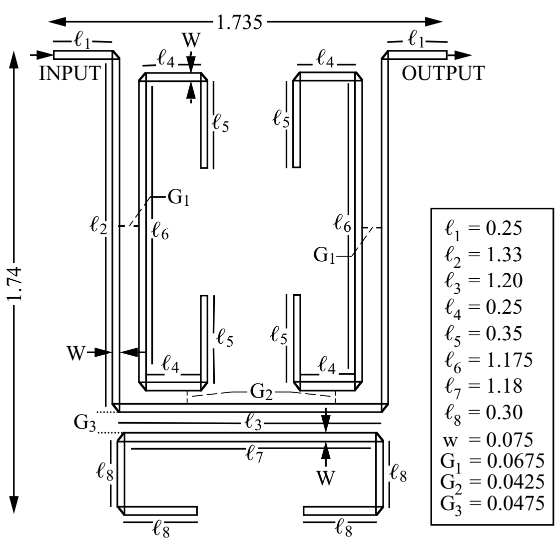

Fig. 1.—Schematic representation of the YBCO/$LaAlO_3$ bandstop filter. All dimensions are in centimeters.

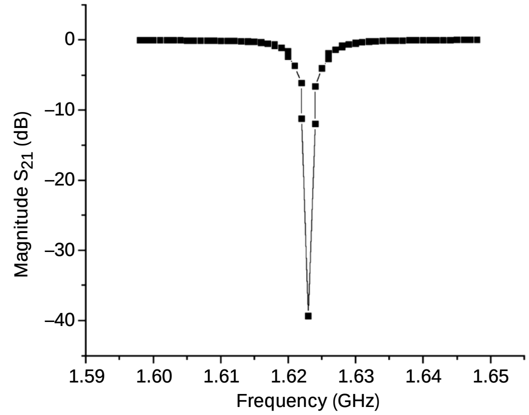

Fig. 2.—Plot of simulated data for the YBCO/LAO filter. The filter has a center frequency of 1.623 GHz, a bandstop rejection of 39 dB, and a bandwidth of 5 MHz at 3 dB. The simulation was performed using Zeland's IE3D electromagnetic simulator.

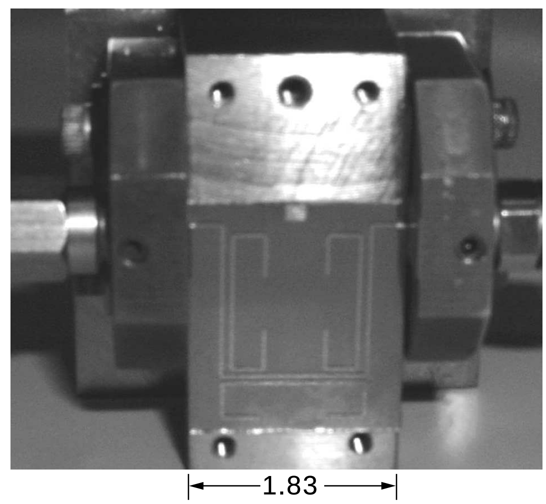

Fig. 3.—The L-band Au/LAO filter mounted on experimental test fixture. The dimension scale is in centimeters.

The microwave characterization of the filter was performed by mounting the filter with silver paint on a custom-made brass test fixture. The microwave signal was launched to the circuit via coaxial SMA connectors. A picture of the filter mounted in the test fixture is shown in Fig. 3. For cryogenic testing of the YBCO filter, the fixture was bolted to the cold finger of a helium gas, closed-cycle refrigerator modified with a vacuum shroud with coaxial feedthroughs for input and output connections to an HP 8510C network analyzer. Measurements were taken under a vacuum of less than 1 mtorr.

A tunable version of the filter was also studied. This version was optimized based on the multilayer structure shown in Fig. 4(a), for a ferroelectric thickness of 300 nm, dielectric constant of ε_{rSTO}=1500 and loss tangent of tanδ=0.01, which are conservative parameters for STO ferroelectric thin films [10]. Because of the ferroelectric, the optimized design for this version shown in Fig. 4(b) differs from that shown in Fig. 1 for the YBCO/LAO filter. The performance of the YBCO/STO/LAO filter obtained using IE3D is shown in Fig. 5. Note that the filter can be tuned by 2 percent to both sides of the center frequency (1.623 GHz) without degrading the specifications outlined earlier in the paper. Beyond these range, although the filter is tunable up to 5 percent with respect to the center frequency, the impedance mismatches introduced particularly for values of ε_{rSTO}>2000 result in filter performance degradation. For the experimental characterization of this filter, dc voltage was applied through gold wire bonds directly connected to the poles of the filter while keeping the transmission line grounded.

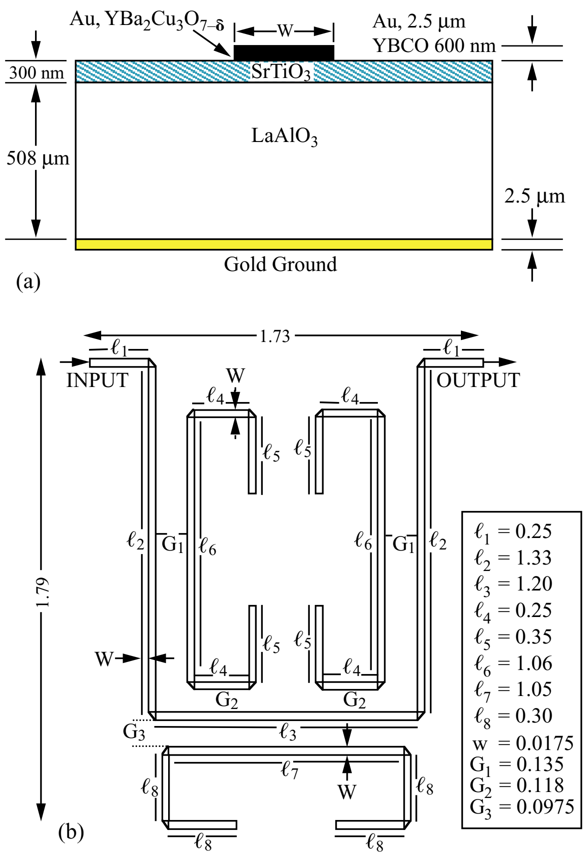

Fig. 4.—(a) Modified microstrip line structure for ferroelectric-base L-band tunable filter. (b) Schematic representation of the YBCO/STO/LAO bandstop filter. All dimensions are in (b) are in centimeters.

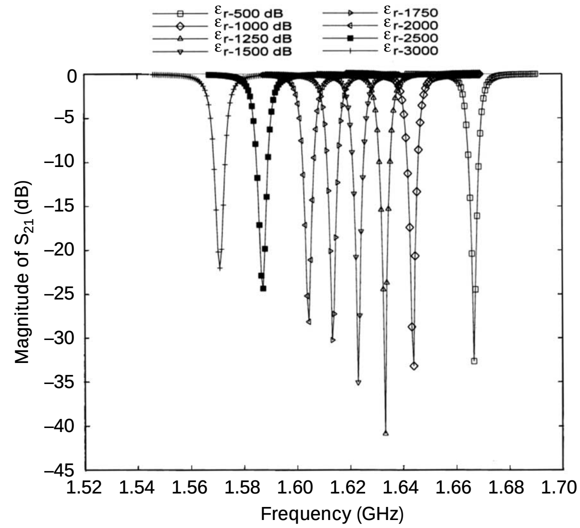

Fig. 5.—Plot of simulated data for the YBCO/STO/LAO filter for different values of STO's dielectric constant and for tan**δ** = 0.01.

III. Results

The performance of the Au/LAO version for the fixed-frequency L-band filter is shown in Fig. 6. The filter exhibits a rejection greater than 32 dB at 1.625 GHz (only 2 MHz away from specifications) and insertion losses of less than 1 dB away from the rejection band (markers 2 and 3, Fig. 6). However, the 3 dB bandwidth of the filter is ~47.5 MHz, which is 9 times wider than the specifications. Not withstanding, these are impressive results given the fact that the optimization process was done for a superconducting filter. This filter exhibited a loaded Q~650 at room temperature.

Figure 7 shows the performance of the YBCO/LAO filter. Data were taken at 60 K, which was the temperature at which the filter exhibited the best performance, possibly due to nonoptimal film quality. In this case the filter exhibits a 3 dB band-width (markers 5 and 4) of ~5.5 MHz, which is very close to the specified bandwidth. However, it shows a rejection of only 24 dB at 1.6471 GHz and an insertion loss away from the bandstop frequency worse than those for the Au-filter counterpart, again possibly due to film quality limitations. This filter exhibited a loaded Q~3660. The performance of this filter should be improved by using high-quality, double-sided HTS films.

Figure 8(a) shows the performance as a function of temperature of an Au/STO/LAO version of the filter shown in Fig. 4. Note that the reject frequency shifted by 47.5 MHz from 298 to 45 K. Note that the better performance of the filter is realized at 45 K where the value of ε_r should be above 1000. Figure 8(b) shows the performance of this filter when applying 300 Vdc to the filter's poles (E_{max} = 0.63 V/µm), which resulted in a frequency shift of nearly 2 percent, consistent with simulations. Although the tunable filter did not live up to all the specifications of the simulated performance shown in Fig. 5, its performance could be improved by using STO films with higher ε_r and larger dc bias.

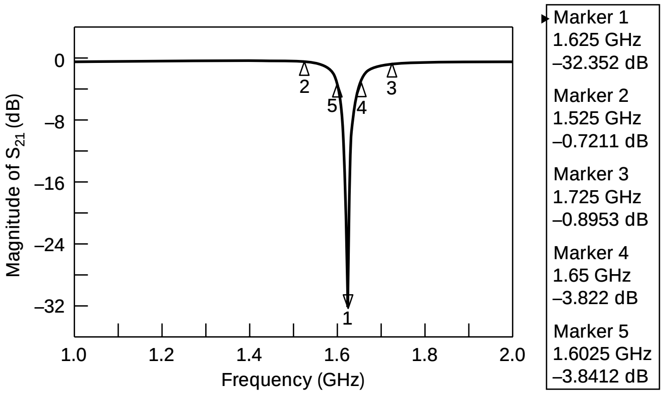

Fig. 6.—Experimental performance of the Au/LAO L-band, 3-pole bandstop filter at room temperature.

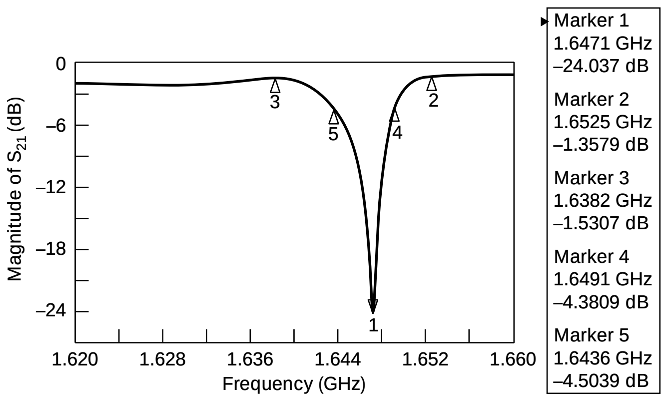

Fig. 7.—Experimental performance of the YBCO/LAO L-band, 3-pole bandstop filter at 60 K.

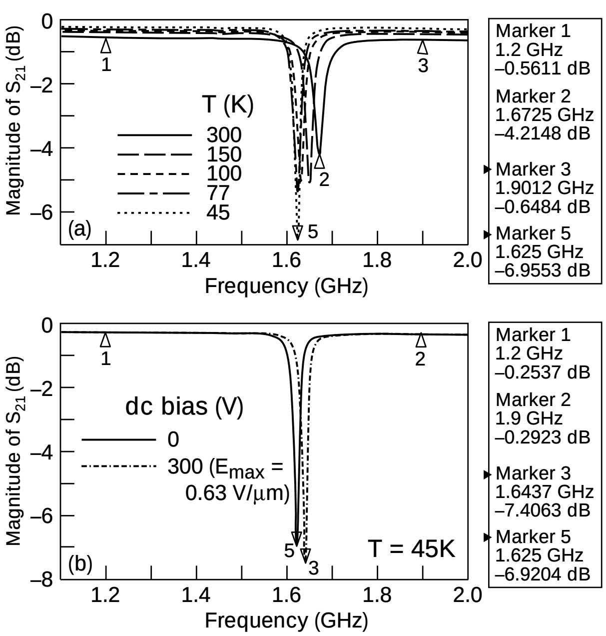

Fig 8.—Experimental performance of an Au/STO/LAO L-Band, 3-pole bandstop filter as a function of temperature (a) and dc bias voltage (b).

IV. Conclusions

In this work, a compact, highly selective (Au,YBCO)/LAO microstrip bandstop filter has been demonstrated for L-band applications. Both the HTS and gold versions of this filter show promising performance to comply with the stringent specifications upon further optimization. The HTS circuit had a 3 dB band rejection bandwidth of ~5.5 MHz, compared to ~47.5 MHz for the gold counterpart, and a rejection of 24 dB, which could be improved using very high-quality, double-sided YBCO thin films. We have also shown the feasibility of a frequency tunable version for this filter. Simulated data for a YBCO/STO/LAO filter predict at least 2 percent tunability while maintaining specifications. Attainment of this level of tunability has been demonstrated with an Au/STO/LAO version of the filter. Experimental work is currently underway for optimization of the YBCO/STO/LAO tunable bandstop filter.

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13. ABSTRACT ***(Maximum 200 words)***

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14. SUBJECT TERMS

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